A Pilot Study of Radon Levels in Certified Passive House Buildings

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Abstract

The international Passive House Standard delivers high thermal comfort based on the principles of excellent building fabric and balanced mechanical heat recovery ventilation. Considering that the typical person in industrial countries (such as the UK) spends ~90% of their time indoors, there are surprisingly few academic studies on air quality in the home. Indoor air quality and the prevalence of overheating are attracting an increasing amount of research attention across Europe but post occupancy monitoring of indoor radon concentrations is severely underrepresented, especially in Ireland and the UK. Radon is a naturally occurring radioactive gas and known carcinogen that presents a potential risk to occupier health.
This pilot study investigates measured radon levels in Northern Ireland certified Passive House buildings and presents an overview of technical radon prevention design options for new builds and mitigation measures for existing buildings. Initial findings indicate that buildings built to the Passive House Standard correspond with reduced indoor radon gas concentrations.

Keywords Certified Passive House, EnerPHit, Radon, IAQ, Indoor Air Quality

Practical Application

This Technical Note addresses an issue pertinent to the industry at this time. The growth of energy efficient standards (such as Passive House) and common principles (such as increased airtightness levels and mechanical ventilation systems) has accelerated the need for research data on indoor radon concentrations. This research bridges the knowledge gap between the fields of indoor air quality (specifically radon), health, sustainability and the built environment.

1.0 Introduction

Implementation of the new, legally-binding Paris Agreement on climate change has reinforced the need to reduce energy consumption in buildings. Currently European buildings account for ~40% of the total energy consumption within the European Union (EU) [1]. The Energy Performance in Buildings Directive (EPBD) mandates that all EU member states build near zero energy buildings (NZEB) by 2021 [2]. The EPBD defines near zero energy buildings, in broad terms, as those buildings with high energy efficiency performance. The directive states that the very low amount of energy required should be provided to a very significant degree by energy from renewable sources, preferably produced on or near-site [2].

The international Passive House Standard offers a proven methodology to achieve this goal. As a building standard that is energy efficient through a reduction of consumption and a reduction of greenhouse gas emissions, the Passive House Standard has emerged as a key enabler for the NZEB standard. The combination of Passive House with renewable energy production presents a suitable solution to move to low/zero carbon. Passive houses focus on energy saving and is designed to have an energy demand that is as low as practically achievable. With such a small amount of energy to be supplied, it is easier to meet the subsequent demand with renewable sources [3].

To meet the Passive House Standard the airtightness of a building must achieve an air change per hour rate of less than 0.6 at 50 Pascal's of pressure (n50), and have ventilation provided by a either balanced mechanical heat recovery ventilation or demand controlled ventilation systems. Existing research has focused on Indoor Air Quality (IAQ) and, in particular, overheating risks in Ireland and the U.K. [4]. None have investigated the relationship between the unique characteristics of certified Passive House buildings and indoor radon concentrations.

The objective of this study is to assess if a certified Passive House building, with the associated high levels air tightness coupled with mechanical ventilation, will result in a reduction in indoor radon gas concentrations compared to conventional builds. This paper will present the initial research findings from a Northern Irish sample (Figure 1) taken from a larger PhD study investigating indoor radon concentrations in Irish and UK certified Passive House buildings.

The coloured areas in Figure 1, below, represent a 1% or greater probability of the radon level in a dwelling exceeding the action level of 200 Bq/m^3 which are known as 'radon affected areas' [5].

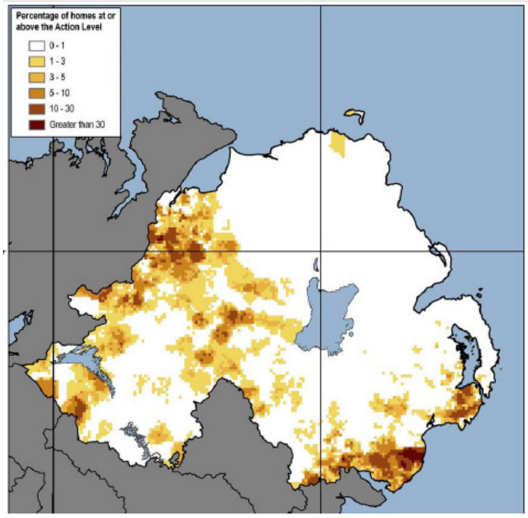

Figure 1 – Radon affected areas in Northern Ireland.

2.0 Radon in Buildings

The World Health Organization (WHO) has identified radon as a known human carcinogen, with a wealth of biological and epidemiological evidence connecting radon exposure and lung cancer [6]. Radon is estimated to cause 30 deaths per year in Northern Ireland and is the second largest identified cause of lung cancer after smoking. Public Health England (PHE) estimates that some 155,000 homes (~1 in 5 in Northern Ireland) are in 'radon affected areas'. Households in these areas are exposed to radon at a level where protective action is recommended [7].

Radon is a naturally occurring radioactive gas that results from the decay of uranium in rocks and soils and is the major source of ionising radiation exposure to the UK population. Radon decays to form tiny radioactive particles, some of which stay suspended in the air as colourless, odourless, tasteless gas that can only be measured using special equipment. Normally, when radon surfaces into the open air it is quickly diluted to harmless concentrations. However, when radon enters an enclosed space such as a house or other buildings through cracks in floors or gaps around pipes and cables it can build up to a dangerously high concentration. Inhaled radon particles give a radiation dose that may damage cells in the lung [8].

Health Protection Agency (HPA)advice estimates that with an increase in radon concentration of 100 Becquerel's per cubic metre of air (Bq/m^3), the risk of a smoker developing lung cancer increases by up to 31% with a central estimate of 16% [9]. The HPA advises that homes with smokers or ex-smokers should seriously consider reducing radon levels where concentrations are measured above the target level (100 Bq/m^3) because of the substantial risks associated with a combination of smoking and radon exposure.

Radon measurements are normally made with two radon detectors - one in the main living area and the other in a regularly used bedroom, reflecting the parts of the home that are most often occupied. Detectors are left in place for three months. The government recommended 'action level' for radon in homes in the UK is 200 Bq/m^3. Above this level it is recommended that householders take action to reduce their radon levels [8].

3.0 Radon Prevention

Prior to construction it is not possible to predict the radon concentration in a dwelling. However, probability maps are available which show the probability of radon concentrations in areas across the UK. These maps are displayed in a 1 km x 1 km grid and are colour coded by concentration level: 1%-3%; 3%-5%; 5%-10%; 10%-30% and > 30% [10].

In radon affected areas with a radon probability level >1%, preventative measures must be taken when constructing new dwellings, performing alterations, extensions, conservatory and porch extensions (including exempt conservatory and porch extensions) to dwellings and when converting buildings to dwellings through a material change of use [11].

Indoor radon concentration may be mitigated by 2 preventative measures: Basic radon protection and full radon protection. Basic radon protection is provided by a damp-proof membrane modified and extended to form a radon-proof barrier across the ground floor of the building. Full radon protection comprises a radon-proof barrier across the ground floor and provision for subfloor depressurization (a radon sump) or ventilation (a ventilated subfloor void). The radon sump is not initially activated, rather it is capped and available for use as a secondary measure in case the radon-proof barrier is insufficient for reducing radon levels below the action level of 200 Bq/m^3. The requirements for preventative measures will depend on the radon probability levels as can be seen in Table 1.

Probability %	Required Action
0-1%	No protection required
1-3%	Zone 1: Radon membrane required
3-5%	Zone 1: Radon membrane required
5-10%	Zone 1: Radon membrane required
10-30%	Zone 2: Membrane plus provision for subfloor depressurisation
30% or greater	Zone 2: Membrane plus provision for subfloor depressurisation

Table 1 – Radon probability level and required preventative measures 2012.

4.0 Radon Mitigation

The aim of remedial work is to reduce radon levels as much as possible. Several methods can be used to reduce high radon levels by reducing radon flow from the ground to the dwelling including radon sumps, positive ventilation, natural underfloor ventilation and active underfloor ventilation.

Radon sumps may be active or passive. Active radon sumps are the most effective way to reduce indoor radon levels and are powered by an electric fan. Active radon sumps work best under solid floors or under suspended floors if the ground is covered with concrete or a membrane. They reduce even the highest radon levels. Passive sumps (without a fan) reduce radon levels but are less effective than active sumps. They work best with a pipe ending above the eaves of the roof and may be an option for homes with lower radon levels ~300 Bq/m^3.

Sumps can be added following initial construction by making small hole, big enough for a 110 mm pipe, in an exterior wall just below ground level, removing a bucketful of material to create a space just below the floor slab and running a pipe from the space through the wall and up the side of the house to roof level. The system is powered continuously by an electric fan (active).

Positive ventilation is another method of radon mitigation; a small, quiet fan blows fresh air (usually from the roof space) into the building.

Natural underfloor ventilation is present in many homes and some workplaces that have a suspended ground floor with a space underneath. Good ventilation of this space can reduce radon concentrations.

Active underfloor ventilation using a fan to continuously blow air into or extract air out of the space below a suspended floor. This can be used when natural underfloor ventilation is inadequate to reduce radon level [11].

5.0 Passive House Criteria

Passive House (or Passivhaus) refers specifically to the international Passive House Standard as developed, defined and administered by the Passive House Institute in Darmstadt, Germany. Passive House has a very clear set of requirements so it is possible to check if a building meets the definition the Passive House Standard. Rigorous modelling and verification are required in the design and construction stages to meet Passive House certification standards. This research will monitor only Passive House buildings certified by the Passive House Institute [12].

The Passive House Standard employs a mixed mode ventilation strategy combining a mechanical ventilation system including heat recovery (MVHR) from exhaust air that would otherwise be lost and summer ventilation / cooling using windows. Mixed mode ventilation allows for Passive House airtightness / air leakage criteria: 0.6 air changes/hour under a blower door test. This minimises energy loss to outside, improves insulation performance and reduces moisture ingress into the building fabric.

This Standard contrasts sharply with natural ventilation methods where sufficient ventilation for occupants is achieved, in part, due to a leaky building fabric. The resultant draughts in naturally ventilated buildings are often exacerbated by the use of open fires which further draw in air for combustion.

As concerns about indoor air quality and health grow, ensuring good indoor air quality is critical. Available research already indicates that a correctly installed and operating MVHR has a positive effect on IAQ and humidity levels. The Passive House Standard uses the European air quality category IDA 2 (Medium IAQ - CO_2 level = 400-600ppm) to define MVHR operating parameters. The Passive House certification criteria set out key metrics for compliance in respect to MVHR including early design consideration, successful installation and commissioned units. This is confirmed by academic research into the performance of the Passive House Standard [13].

6.0 Radon Testing

6.1 Sample Selection and Characterisation

The sample used in this pilot study is from 5 certified Passive House buildings in Northern Ireland. Table 2 provides details of these buildings including size, year of construction, construction type, Passive House Standard certification type and the air tightness level (n50).

ID	Postcode	Year of Construction	Size (m^2)	Construction	Type	Building	n50
2474	BT78 5	2012	127	Timber	New Build	Detached	0.51/h
2856	BT19 1	2013	185	Timber	New Build	Detached	0.58/h
4749	BT92 6	2014	287	Masonry	EnerPHit	Detached	0.7/h
4751	BT71 6	2014	144	Timber	New Build	Detached	0.6/h
5185	BT74 4	2014	455	Timber	New Build	Campus	0.6/h

Table 2 – Details of selected Passive House buildings for the initial sample

Building characteristics and materials are significant as the most common sources of radon are gas from the soil/ground and off-gassing from building materials containing radon [14, 9]. Building material emissions are much lower than emissions from soil/ground gas and only apply to building materials such as ground rock and those which originate from ground rock such as sand, soil and cement. Concentrations of radon present in these building materials will vary depending upon geological origin [15]. Timber frame construction is the dominant form of construction in this sample and so the building material emissions will be relatively low.

Building ID: 2474 is equipped with a ground air heat exchange system and as such there may be increased radon levels due to leaks or direct air intake from the soil.

It also has to be noted that such as existing house Building ID: 4749 has been retrofitted to the Passive House retrofit standard (EnerPHit). Other studies have shown that energy retrofitting of homes may reduce the potential for ventilation flushing of radon gas from the house, increasing radon levels [16].

Retrofit houses may also have an existing floor that does not include radon protection and sealing the full footprint of the building may prove difficult. Therefore, it is difficult to predict the effect of applying Passive House techniques to existing buildings on indoor radon concentrations: A properly installed and operating MHRV system could reduce the radon level but failing to completely seal the building envelope could increase the radon level [17].

Building ID: 5185 is non-residential so the two most occupied rooms were chosen for testing. If the radon level in any part of a workplace exceeds 300 Bq/m^3 as an annual average, the employer is then obliged to take radon mitigation action to ensure staff safety [18].

6.2 Radon Monitoring

In 2010 the Health Protection Agency (HPA) updated its advice on the limitation of human exposure to radon, maintaining the national action level at 200 Bq/m^3 and introducing the concept of a target level at 100 Bq/m^3 [19].

The target level refers to an annual average concentration of 100 Bq/m^3 or below as the ideal level acceptable for remediation works in existing buildings and protective measures in new buildings [19].

The HPA, WHO and most international governments recognise that homes which exceed the radon action level (200 Bq/m3) should reduce their radon levels with immediate effect. This action level refers to the annual average concentration in a home, so radon measurements are carried out with two detectors (in a bedroom and living room) over three months, to average out short-term fluctuations.

In this pilot study indoor radon levels were measured by CR-39[3] alpha track diffusion radon gas detectors placed in the main living area (Room 1) and the main bedroom (Room 2) for just over 3 months from October 2017 to January 2018. Radon results are presented as arithmetic average (figure 3) and geometric average (figure 4) with corresponding seasonal correction factors.

The test results will also be compared with the existing data on radon in Northern Ireland.

Table 3 presents the arithmetic and geometric average of measured radon levels in each postcode area corresponding to a Passive House building in this pilot study. The averages were taken from ~24,000 radon measurements from homes in Northern Ireland between 1983 and 2015 [19].

ID	Postcode	Total Homes	Homes Tested	Arithmetic Average (Bq m^{-3})	Geometric Average (Bq m^{-3})	Highest Result (Bq m^{-3})
2474	BT78 5	3,200	93	50	40	190
2856	BT19 1	6,400	6	32	20	93
4749	BT92 6	530	63	65	37	540
4751	BT71 6	4,900	56	38	29	180
5185	BT74 4	1,600	17	47	37	110

Table 3 –Radon in Dwellings in Northern Ireland 2009

7.0 Radon Testing - Results

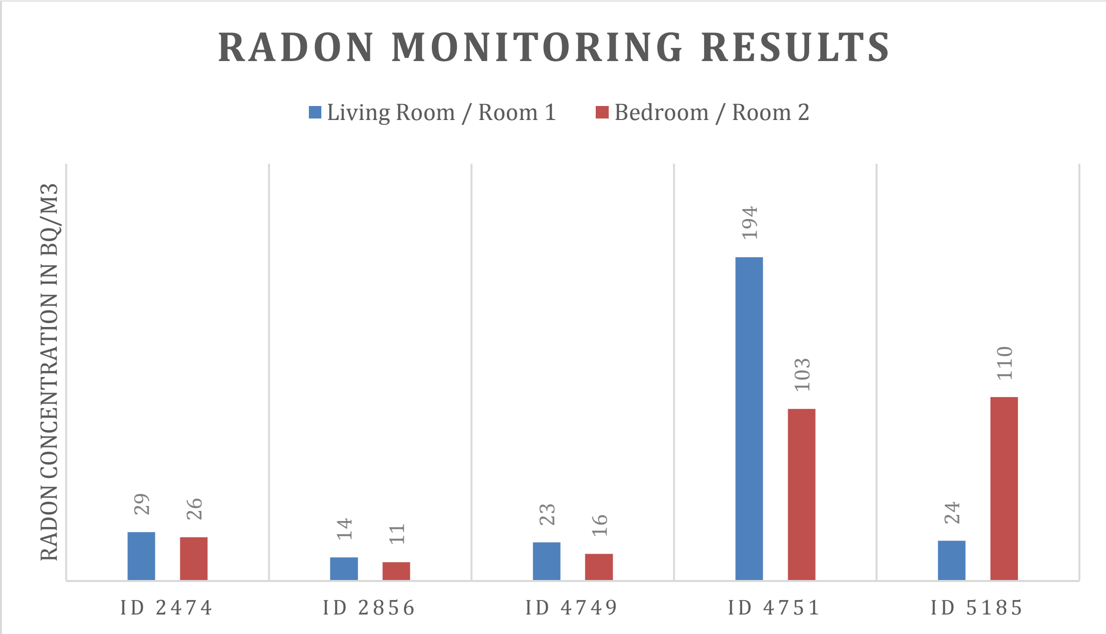

Figure 2 – Radon Monitoring Results.

The initial results for radon concentration in certified Passive House buildings. Radon detectors were located in the living room (room 1) and the main bedroom (room 2). In Building ID: 5185 (a commercial building) the rooms selected were the two most frequently occupied and are labelled Room 1 and Room 2.

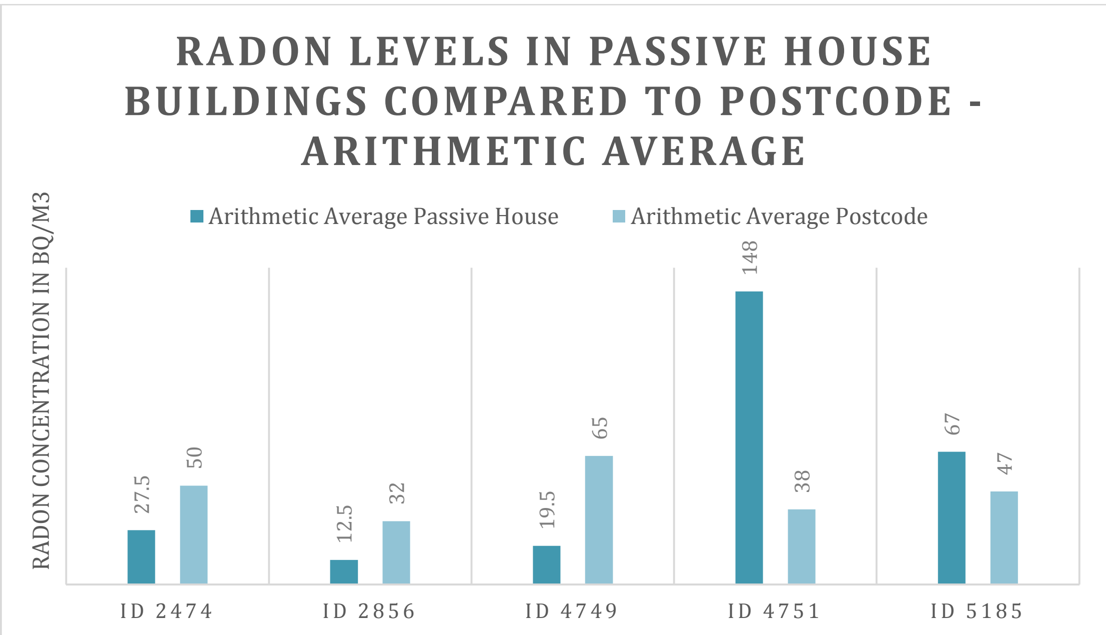

Figure 3 – Radon Monitoring Results Arithmetic Average Comparison.

Arithmetic average comparison of Passive House monitoring results and corresponding postcode reference level in Northern Ireland from Public Health England. The arithmetic average radon results are lower in the Passive House monitoring than the postcode in Building IDs 2474, 2856 and 4749. Passive House radon levels were marginally higher in Building ID: 5185 and significantly higher in ID: 4751. Results indicate levels below the action level (AL) of 200 Bq/m^3 although ID: 4751 is above the target level (TL) of 100 Bq/m^3.

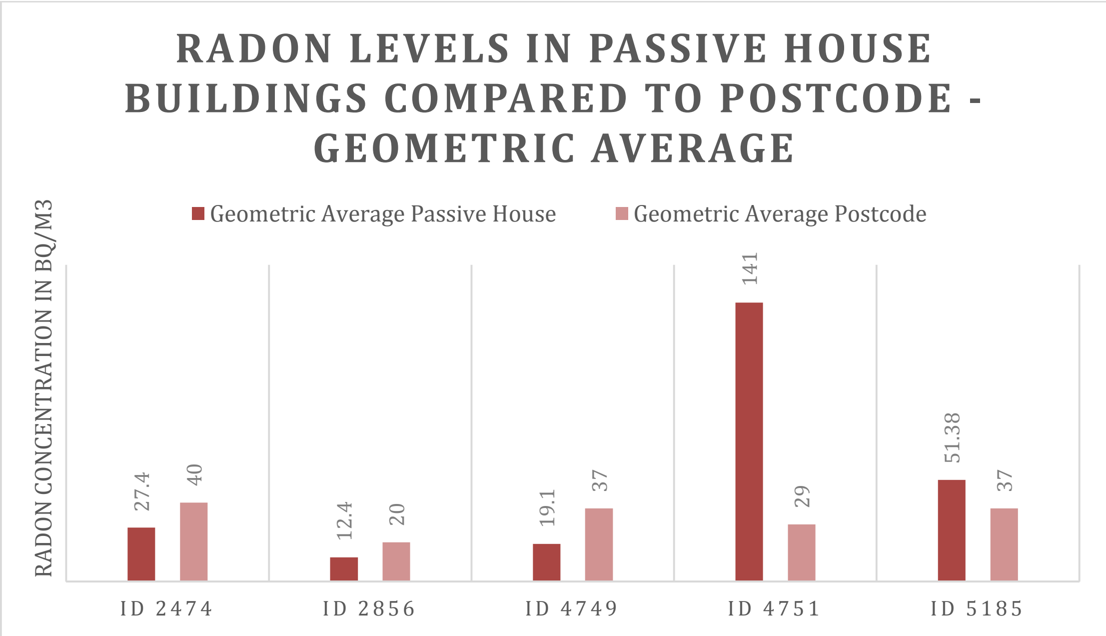

Figure 4 – Radon Monitoring Results Geometric Average Comparison.

Geometric average comparison of Passive House monitoring results and the corresponding postcode reference level in Northern Ireland from Public Health England. All Results indicate levels below the action level (AL) of 200 Bq/m^3. ID: 4751 again however is above the target level (TL) of 100 Bq/m^3.

The outlying Building ID: 4751 is a two story domestic dwelling located it an area with a maximum radon potential is 3-5 %. The monitoring result in both rooms is higher than the radon level for the corresponding postcode.

Building ID: 5185 is a large single storey educational facility built to the Passive House Standard within the same parameters as the other buildings in the sample. The monitoring result is higher than the average radon level for the corresponding postcode. We can see from Figure 2 that room 1 in this building produced a low reading consistent with the rest of the sample and that room 2 produced a reading that was much higher. The result for room 2 was above the target level (TL) of 100 Bq/m^3 recommended by Public Health England. There are various potential reasons as to why this may have occurred such as mechanical ventilation problems [20].

Building ID 4751 and ID 5185 which produced individual indoor radon concentration results above the target level of 100 Bq/m^3, requires further analysis into the ventilation system and its current operation.

The other results provide consistently low readings of indoor radon concentrations for the monitoring period. However, this sample is particularly small and initial findings must be handled with caution until a bigger sample can provide more significant evidence if results continue to follow this pattern. These initial results add weight to similar pilot studies carried out Austria and Belgium [17, 20].

In Figure 5 both the arithmetic and geometric averages from the study are compared against the overall averages for Northern Ireland. This clearly shows lower indoor radon concentrations in the Passive House sample. As the number of houses investigated in this research was very small, the results should be treated with caution, however they correlate with results in similar pilot studies [14, 17, and 20].

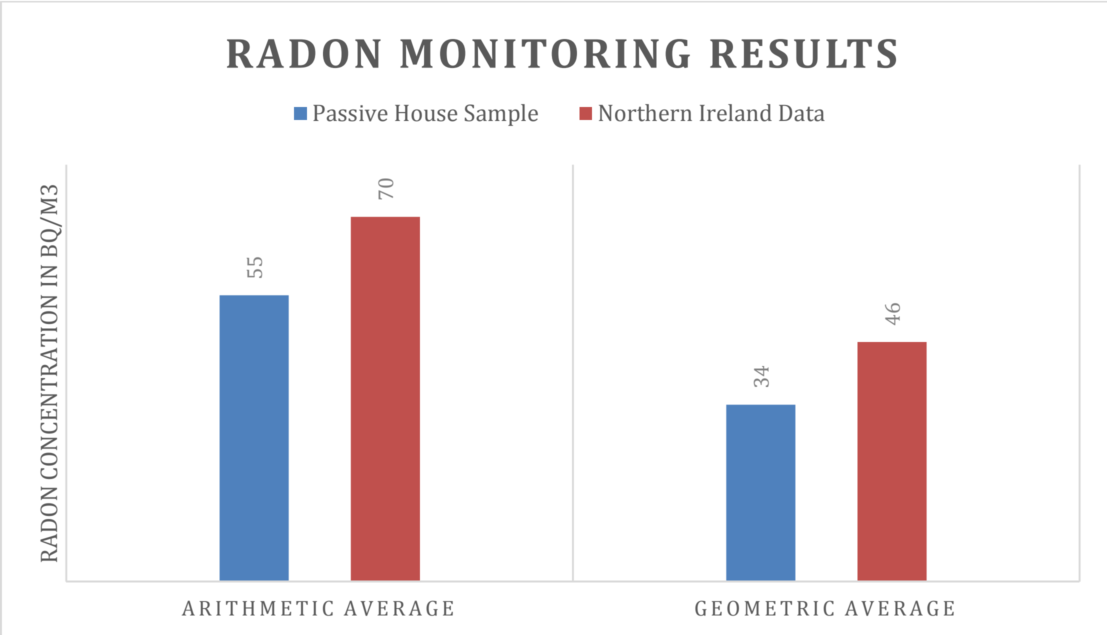

Figure 5 – Northern Ireland Arithmetic and Geometric average comparison

The initial findings of this study also provide some indication for what factors require further investigation.
Building ID: 2474 equipped with a ground source intake for the MVHR system has demonstrated no negative effect on indoor radon concentrations suggesting that this system was installed correctly, an indication of quality assurance.

Building ID: 4749 is retrofitted to the Passive House Standard (EnerPHit) and shows no indication of elevated radon levels for a retrofitted building.

8.0 Conclusion

Radon is a dangerous radioactive gas that is naturally occurring, can accumulate in houses and can increase the risk of lung cancer, especially in individuals who smoke. The Passive House Standard may reduce the levels of radon due to the rigorous standards of airtightness and mechanical heat recovery and ventilation.

This study presents the initial findings of a larger research project into the indoor radon levels in Passive House buildings compared to postcode averages in conventional buildings.

Initial results are consistent with the hypothesis that certified Passive House buildings perform better in respect to indoor radon concentrations compared to postcode averages. Future work will produce a comparative radon study of the certified Passive House standard buildings and buildings built to the prevailing building regulations in the UK and Ireland.

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